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Damage Control Automation for Reduced Manning (DC-ARM) Supervisory Control System Software Summary Final Report

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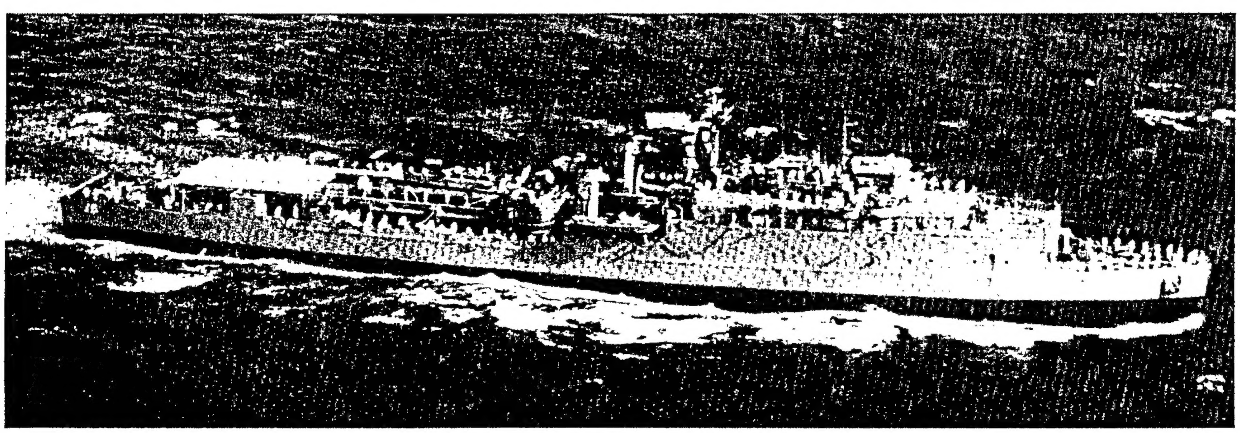

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14. ABSTRACT

The development of the DC-ARM Supervisory Control System (SCS) is discussed. The SCS is used to provide situational awareness of a ship casualty to the operator through a variety of means. The SCS currently interfaces and controls the ship's automated fire main, outfitted with smart valves, a high-pressure water mist system, a video over IP system, a door position indication system, and environmental sensors. Testing aboard the SHADWELL demonstrated that situational awareness can be achieved within 5 seconds after the casualty and that automatic fire boundary containment can be completed within 25 seconds. The SCS can also automatically reconfigure damaged ship systems (such as a ruptured fire main) in approximately 1 minute.

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Damage Control Automation for Reduced Manning (DC-ARM) Supervisory Control System Software Summary Final Report

1.0 Introduction

The Damage Control Automation for Reduced Manning (DC-ARM) Program was started in 1997 to develop and demonstrate technology for enabling reductions in the manning needed for damage control (DC) while, at the same time, improving DC performance. The DC-ARM Program is sponsored by the Office of Naval Research (ONR) and managed by the Naval Research Laboratory (NRL). Testing to support DC-ARM development and DC-ARM demonstrations was conducted aboard NRL's fire research test ship, the ex-USS *Shadwell* in Mobile, AL [1].

The DC-ARM Program has been a multi-year effort designed to evaluate and demonstrate incremental reductions in DC Manning corresponding to increases in automation and doctrine improvement through scientifically based experimentation. The DC-ARM technologies selected to enable reduced DC manning included:

- Water mist for fire suppression and fire containment.
- Instrumentation for fire detection and fire characterization.
- Fire main distributed controls for robust, survivable isolation of fire main ruptures.
- Smoke ejection system for clearing smoke on the DC deck.
- Access closure monitoring to improve situation awareness.
- Video installed in most spaces for compartment monitoring and to reduce investigation workload.
- Supervisory control system (SCS) to enable effective situation awareness and overall control of the DC response.
- New doctrine developed to integrate with new technology

The DC-ARM technology demonstrations included a variety of peacetime fire scenarios (self initiated fires) and wartime damage scenarios. The wartime damage scenarios replicated the damage expected from a anti-ship missile hit, one of the most stressing DC events. The wartime damage included structural damage, damage to accesses, fire main damage, damage to instrumentation and control systems, major fires, smoke, and flooding. Fleet personnel actively took part in the live fire and flooding tests to exercise the DC-ARM systems and reduced manning doctrine in a realistic shipboard damage environment.

References [2] and [3] are NRL reports of the FY98 and FY00 DC-ARM demonstrations respectively. Reference [4] reports the first phase of the SCS development. This report is a summary of the DC-ARM SCS development; it addresses:

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- Performance demonstrated,
- SCS functions from the perspective of DC personnel,
- SCS architecture and application program functions,
- A methodology for engineering the architecture distributed control systems, and
- Conclusions and recommendations.

As used in this report, an SCS is defined as: A system, automated to some extent, that monitors and controls multiple ship systems and enables a human supervisor to interact with the ship systems through a human-computer interface and to manage human actions so that the responses of the systems and the actions of the personnel complement one another.

2.0 Performance

The SCS, combined with the other DC-ARM technology, enabled effective management of the DC response during the FY01 Demonstration. The performance demonstrated is summarized in Table 1 and described briefly below for Casualty Characterization, Fire Containment, Fire Control, Fire main Rupture Isolation, and DC Management.

2.1 Casualty Characterization

The information provided by the SCS significantly reduced the time required to identify the Primary Damage Area (PDA). The Primary Damage Area is defined as the area subject to the immediate effects of the weapons in particular, structural damage, equipment damage or personnel injury caused by weapon blast or fragments from the weapon [5]. Defining the PDA historically has involved dispatching investigators and waiting for their reports of damage; this typically has taken 15 minutes or more. During the Baseline Demonstration, without the SCS, it took an average of 18 minutes to define the PDA. Until the PDA has been defined, the DC team cannot plan and execute an effective course of action. With the information and decision aids provided by the SCS, it took less than 4 seconds to display the PDA. With this more rapid casualty characterization, DC actions can be executed much sooner. For example, water mist was actuated to contain the fire within 25 seconds after weapon impact.

The SCS defines the PDA as all contiguous compartments that the SCS believes were affected by the same casualty-initiating event. To determine which compartments are included in the PDA, the SCS looks at all available environmental sensors and categorizes the data and sensor as normal and functioning, abnormal and functioning, or nonfunctioning. Generally, contiguous compartments with abnormal data or nonfunctioning sensors are categorized as belonging to the PDA.

Table 1. Summary of DC-ARM Key Performance Demonstrated
Shading denotes meeting DC-ARM Objective

DC-ARM Objectives		Baseline Demo – FY98 *No SCS Used*	FY00 Demo *SCS w/ only Remote Manual Control*	FY01 Demo *SCS w/ Automation*
Identify PDA	**≤ 9 min.**	18 min.	3.3 sec.	3.75 sec.
Extinguish Fires in PDA	**≤ 33 min.**	62.5 min.	40 min.	37 min. 10 sec.
Set Vertical Boundaries	**≤ 9 min.**			
Manually		19 min. 23 sec.	NA [2]	NA [2]
Using Water Mist		NA [1]	2 min. 35 sec.	0 min. 25 sec.
Set Horizontal Boundaries:	**≤ 13 min.**			
Manually		13 min. [3]	6 min. 15 sec.	4 min. 48 sec.
Using Water Mist		NA [1]	1 min. 48 sec.	0 min. 25 sec.
Isolate Fire main Rupture	**≤ 9 min.**	13 min. 15 sec. [4]	1 min. 48 sec.	1 min. 22 sec. [5]

Notes:
1. Water mist system not installed for the Baseline Demo.
2. No manual vertical fire boundaries were required. All vertical fire boundaries were set/maintained using the water mist system.
3. Horizontal fire boundaries could not be maintained in all tests.
4. Using only manual isolation.
5. Rupture isolation actually occurred in approximately one minute. The rupture and associated isolation information was displayed to the DC Officer at 1 min. 22 sec.

PDA = Primary Damage Area
The times shown are the averaged time for all wartime tests in a test series.
Data presented in Table 1 obtained from the following references:
DC-ARM Objectives and Baseline Demo performance data from Reference 2.
FY00 Demo performance data from Reference 3.
FY01 Demo performance data from working notes for preparation of report of the FY01 Demonstration.

2.2 Fire Containment

In the FY01 Demonstration within 25 seconds after weapon impact, the SCS actuated the water mist system in the compartments surrounding the PDA to contain the fire. The SCS monitored the ambient conditions in each boundary compartment and automatically actuated water mist when the boundary temperature threshold was exceeded in a compartment. After the initial actuation, water mist was actuated intermittently in the compartment to minimize the amount of water used. This actuation approach was used to reduce mist, to improve visibility and to minimize collateral water damage. The SCS also provided recommendations that the DC Officer dispatch boundary men to locations that required fire boundaries that were not covered by the water mist system. With the rapid information provided by the SCS, the DC Officer could establish manual fire boundaries (person on-scene with hose, ready to cool bulkheads) in less than 5 minutes. During the Baseline Demonstration without the SCS, it took over 19 minutes to set vertical boundaries allowing the potential for fire spread. Previous fire tests have demonstrated that vertical fire spread can occur in less than ten minutes over a post-flashover fire compartment [2]. With only water mist to contain the fire, some small fires ignited in boundary spaces where combustible material was in direct contact with a bulkhead bounding the PDA. The water mist controlled such small fires until investigators arrived, extinguished the fire, and removed the combustible material from the heated surfaces.

2.3 Fire Control

Using information and decision aids in the SCS, the DC Officer directed a methodical response to damage that utilized manpower efficiently and proved to be very effective at controlling damage spread. In less than 30 minutes, the DC teams accessed the PDA and controlled fires. Fires in the PDA were extinguished within 40 minutes. This performance exceeds, substantially, the performance demonstrated in any non-DC-ARM test aboard the SHADWELL in over a decade of DC testing with Fleet personnel. Table 1 summarizes the performance demonstrated.

The substantial improvement in performance for controlling fire is attributed to the fire containment systems, automatic fire main rupture isolation, the enhanced situation awareness enabled by the SCS, and the decision aids provided by the SCS. Since the fire containment was mostly automatic, and the fire main rupture isolation was fully automatic, the DC Officer was able to devote more attention to fire control. The enhanced situation awareness enabled a clear understanding of where the fire was so that the fire attack could be planned and initiated quickly and conducted effectively. Finally, the SCS decision aids provided guidance that contributed to the efficient, effective use of limited manpower.

In the wartime scenarios exercised during the FY01 demonstration, the SCS decision aids recommended first an indirect fire attack from the compartment above the PDA. The indirect attack was recommended to cool the fire spaces, thereby minimizing the threat of fire spread and improving the environment for a direct attack. The SCS decision aids then recommended an access to the PDA. If information in the SCS indicated all accesses to the PDA were damaged or inaccessible, the decision aids recommended that a DC team cut an access into the PDA. An attack team then entered the PDA via the cut access for a direct attack on the fires. Although the FY01 performance of fire extinguishment in 37 minutes did not meet the DC-ARM objective of 33 minutes, the performance was close to the objective and better than the Baseline and FY00 performance of 62 minutes and 40 minutes respectively.

2.4 Fire Main Rupture Isolation

Fire main rupture isolation is critical because setting manual fire boundaries and initiating manual fire attack cannot occur if the fire main is not operational. The SCS monitors the fire main conditions using information supplied by sensors in Smart Valves (also developed under the DC-ARM program) installed on the fire main. Both the Smart Valves and the SCS are capable of rupture detection and isolation independently. For the FY01 SCS demonstration, the SCS was used as the primary rupture detection and isolation mechanism, with the Smart Valve device level logic (rupture path logic) operating as a backup to the SCS [6]. In the FY01 Demonstration, the SCS isolated the rupture and restored fire main pressure to the undamaged areas in just over a minute. This is a significant improvement from the Baseline Demonstration where it took over 13 minutes to manually locate and isolate the same fire main ruptures, using fire main control similar to that in DDG 51 Class ships.

2.5 DC Management

Also important is the subjective evaluation of the DC Officer's management and control of the situation. During the FY01 Demonstration, DC Central operated in a very efficient manner, it was clear that the DC Officer had good situation awareness, was confident in the ability of his people and systems, and in control of the situation. This is an improvement over the situation during the FY00 Demonstration (with less situation awareness and no automation) and a significant improvement over the Baseline Demonstration when there was more confusion and much less situation awareness.

3.0 SCS Functions

The SCS performs the following functions:

- Controls the fire main
- Controls the water mist system
- Provides fire alarm and fire characterization information

- Provides video surveillance of compartments
- Provides access closure information
- Provides for the entry of information from verbal reports
- Provides a simulated combat system interface with threat status information
- Provides the ability to define operational priorities that would influence DC priorities
- Provides displays to characterize damage
- Provides decision aids to assist with managing the DC response
- Provides casualty simulation to facilitate training

Each of these functions and the DC central arrangement are summarized below.

The SCS logical functions and displays were "human engineered." There are two basic parts to this human engineering process. First, is a rigorous method for determining the functions that personnel must perform and, thereby, determining the information that they need to perform those functions. Second, is the structure and format of the displays so that the information is provide to, or obtained by, the user in a natural, intuitive manner.

The functional analysis method used to define functions is described in section 5.1. Established human factors guidance for human-computer interfaces was studied, tailored to shipboard DC functions, and applied to the development of the SCS displays. Rapid prototypes of various display formats were tested and evaluated by personnel independent from the development and selected display formats and structures were tested with Fleet personnel experienced in DC.

As a result of the comprehensive attention to human engineering design, the displays proved to be quite intuitive and natural for Fleet users. Personnel typically became proficient at difficult tasks with very little training and were able to easily retrieve information they wanted. Most importantly, the SCS clearly enabled the user to achieve superior situation awareness and management of the DC response.

3.1 Fire Main Control

See Figure 1; the SCS provides:

- A human engineered interface for enabling situation awareness of the fire main status and for remote control of the fire main. This includes decision aids for isolating fire main ruptures (if device level and system level controls fail) and for alerting the DC Officer of inoperable fire plugs. The system display is integrated with compartment status information to assist the DC Officer with the difficult task of integrating systems information and compartment information.

- Redundant, survivable system level control to isolate fire main ruptures. This was the primary means of isolating fire main ruptures during DC-ARM exercises.

- Interface with the Smart Valve device level controls for isolating fire main ruptures. The Smart Valves provide a highly survivable, robust rupture isolation capability should communications or system level controls fail. The Smart Valves were developed by another DC-ARM project [6].

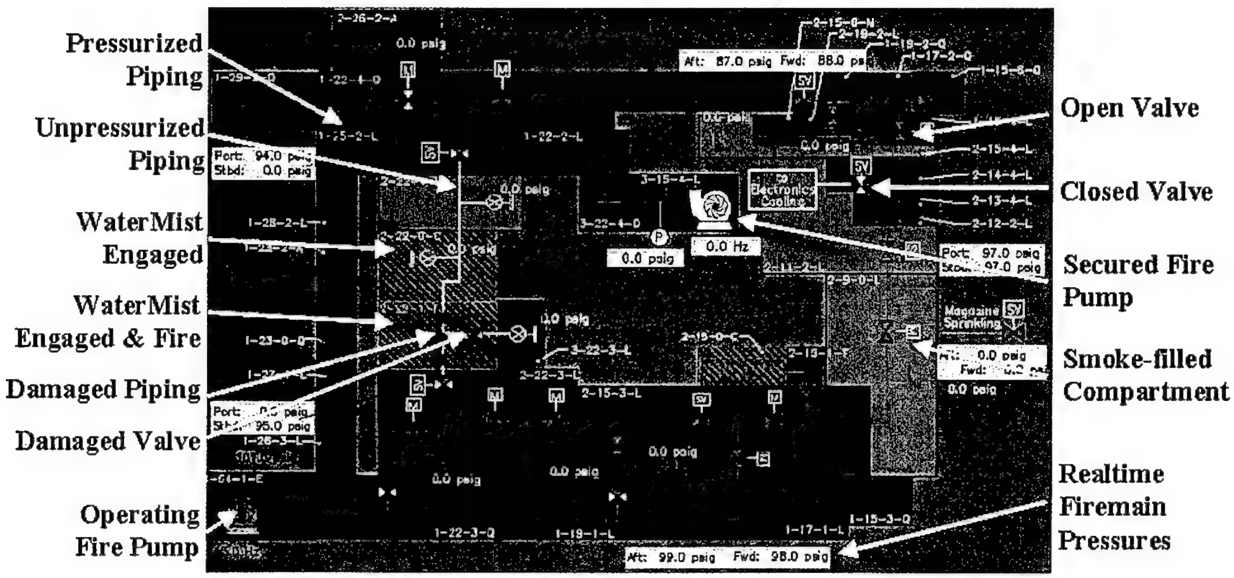

Figure 1. Fire Main Control Display

3.2 Water Mist Control

See Figure 2; the SCS provides:

- A human engineered interface for enabling situation awareness of the water mist system status and for remote control of the water mist system.

- Automatic control of the water mist system for fire suppression and fire containment. This automation is based on fire characterization and fire growth models in the SCS [7], [8] and [9].

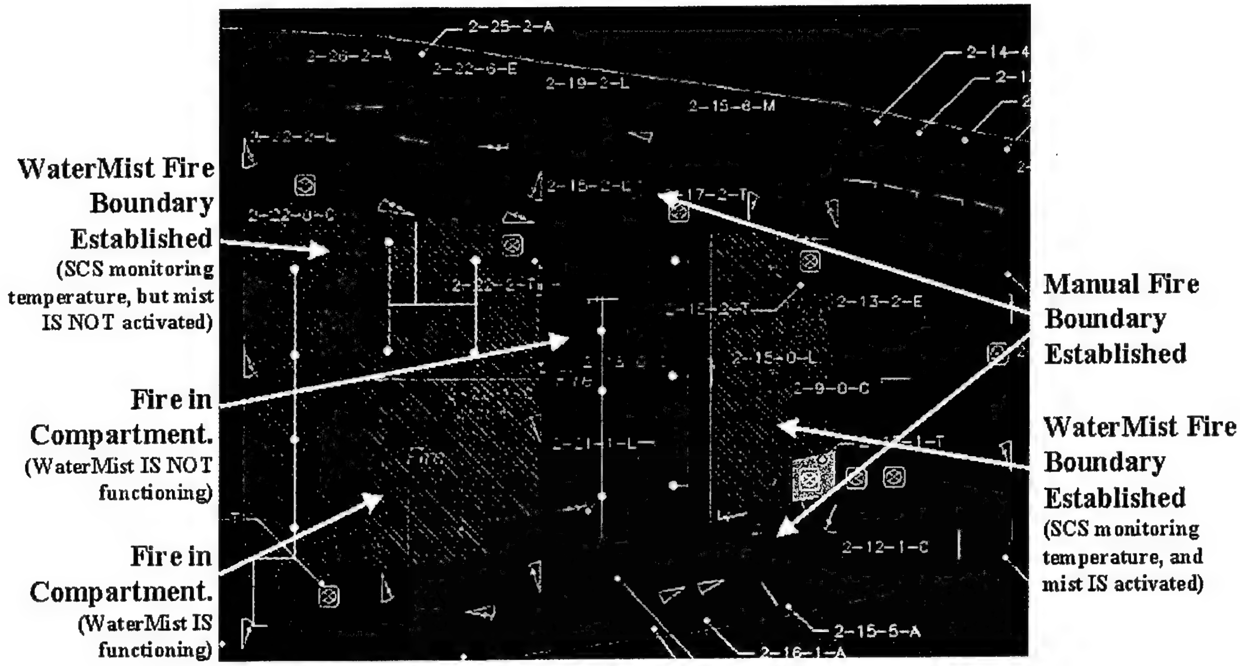

Figure 2. Water Mist Control Display

3.3 Fire Alarm and Fire Characterization

The SCS interfaces with the fire detection system to alert the operator to fire alarms [10]. And, the SCS interfaces with the SHADWELL's instrumentation system to obtain thermocouple data for characterizing fires. The fire characterization, based on fire growth models and available thermocouple data, is used to support decision aids for the type of response appropriate to the fire, the level of personnel protection needed and the need for and location of fire boundaries.

3.4 Video Surveillance

The SCS interfaces with the SHADWELL's video system and enables the operator to select compartment videos to display. The video system also automatically delivers images related to the damage event to assist the DC Officer make a rapid assessment of the situation. The FY00 test concluded that video surveillance would be a significant contribution to situation awareness. The FY01 test confirmed that integrated streaming video was extremely beneficial in the DC Officer's understanding of the casualty. It allowed the DC Officer a first hand view of the entire area surrounding the PDA, complementing the on-scene investigator's reports. Using the integrated video, the DC Officer was able to continually monitor the areas surrounding the PDA faster than investigators would be able to navigate around the PDA and report back to the DC Officer providing quicker visual situational awareness than through only on-scene investigation.

3.5 Access Closure Monitoring

The SCS interfaces with the access closure monitoring system to display the status of access closures [11].

3.6 Data Entry

The SCS provides a human computer interface tailored to entering status data obtained from verbal reports. Past experience with computerized DC information systems demonstrated the need for an interface that enabled the rapid, accurate entry of data from verbal reports. To meet this need, the SCS includes a display engineered to support the rapid entry of data from verbal reports following standard convention for DC reports.

3.7 Threat Status from Simulated Combat Systems Interface

The SCS provides a simulated interface with combat systems to alert personnel to the threat status and to predict damage from an incoming threat weapon (see Figure 3). The predicted threat information is used for decision aids such as stationing personnel away from the threat trajectory (i.e. stationing personnel on the port side when the threat is from the starboard side).

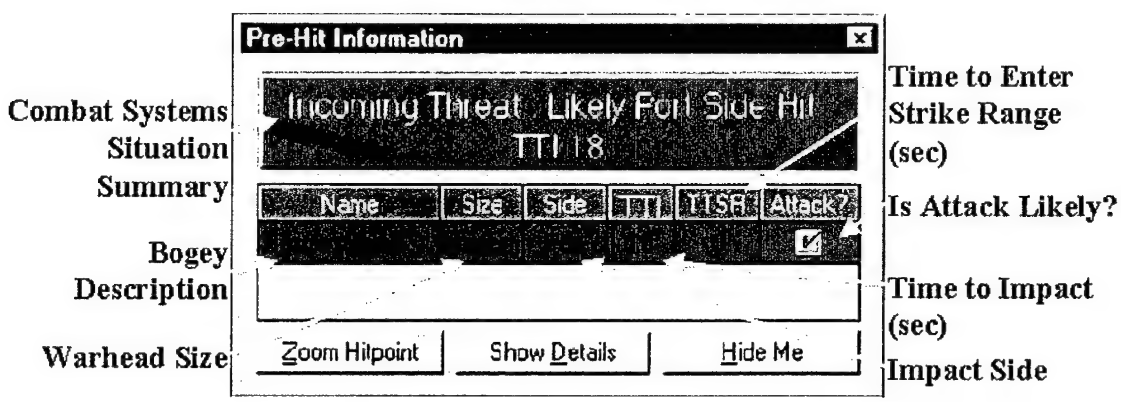

Figure 3. Pre-Hit Information

3.8 Define Operational Priorities

The SCS provides the user with the ability to define priorities among operational elements (maintain mission capability, save the ship, minimize risk to personnel). The defined operational priorities influence DC priorities as follows. Individual compartments are ranked in importance to each operational element. Decision aids then recommend DC actions based on the importance of associated compartments relative to the selected operational priorities. For example, if minimizing risk to personnel is given a very high priority relative to other operational elements, then

controlling damage in passageways and major accesses (for escape and rescue and assistance) would be given a higher priority than controlling damage in combat systems spaces (see Figure 4).

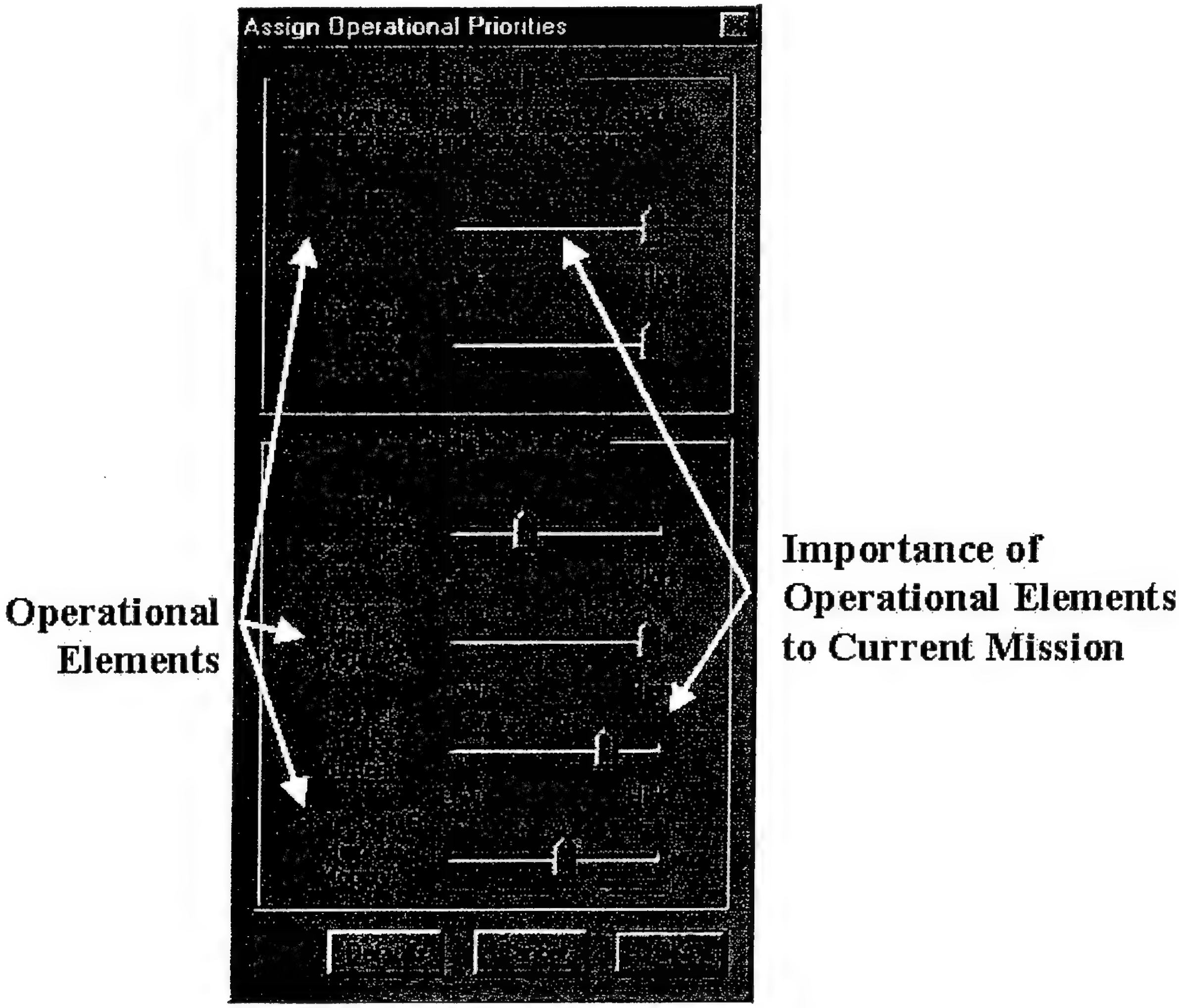

Figure 4. Operational Priorities

3.9 Characterize Damage

The SCS provides human engineered displays of compartment damage (i.e., fire, flooding, smoke and blast damage) and the status of DC actions (i.e., setting boundaries and fire attack) (see Figure 5). Systems information also can be shown on this display although typically system information is not shown.

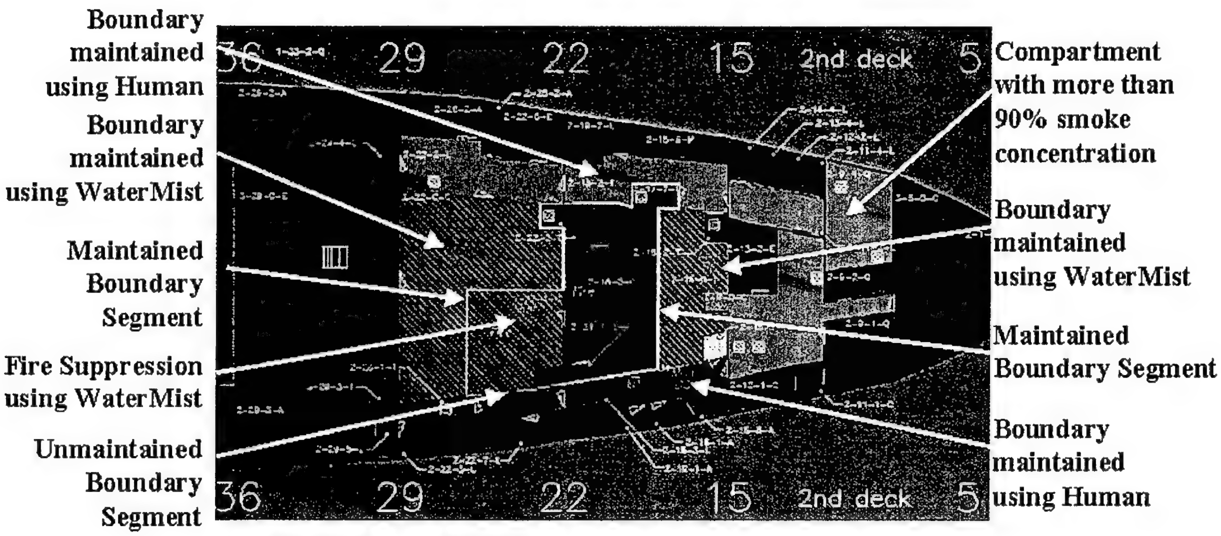

Figure 5. Compartment Damage

3.10 Decision Aids

The SCS provides decision aids to help the DC Officer coordinate the actions of personnel with the actions of ship systems (see Figure 6). Decision aids include functions such as:

- The type of personnel protection required for fire attack teams considering the state of the fire, predicted fire growth, and the time needed for personnel to reach the scene.
- The need for manual boundaries considering the predicted fire growth, the status of water mist, and the importance of the compartment to operational priorities.
- Priorities for investigators considering the estimated extent of damage and the availability of video in compartments in and around the damage area.
- Provided a course of action to attack the PDA based on the human resources available and the current situation. The SCS will continually refine its decisions and recommendations as the scenario evolves, taking into account the effectiveness (or non-effectiveness) of personnel assigned to a particular task or a change in environmental conditions.

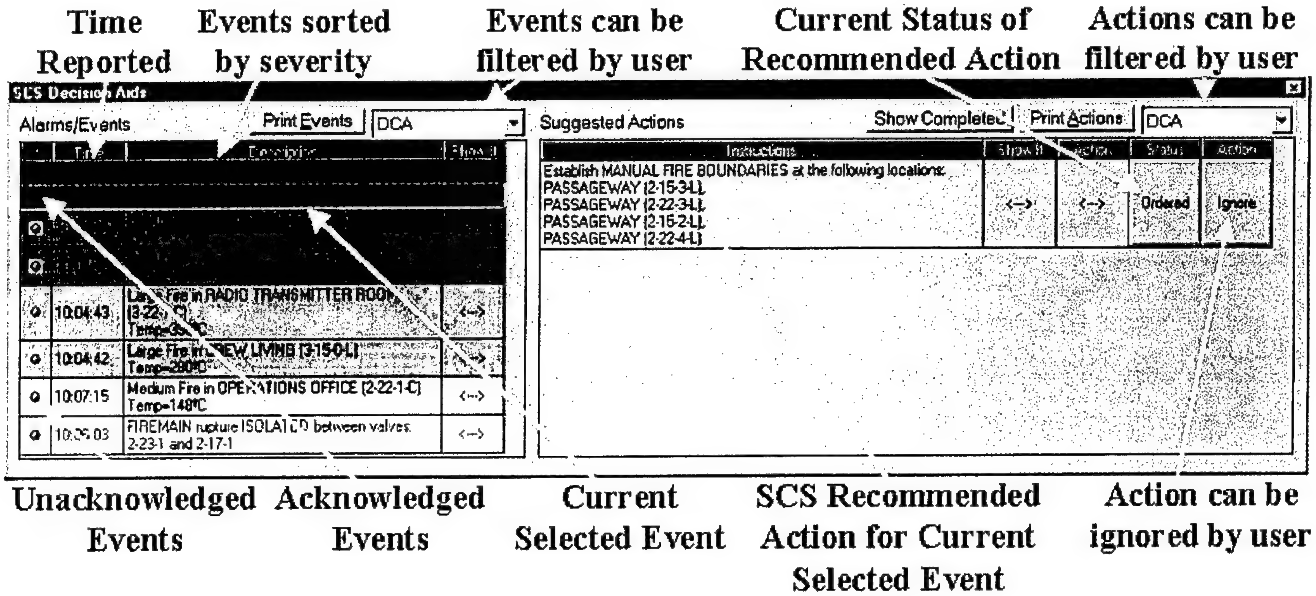

Figure 6. Initial Decision Aids for a Typical Wartime Scenario

3.11 Simulation and Training

The SCS was designed with a training feature that allows users to exercise the SCS against hypothetical scenarios. Each scenario is designed around a blueprint of the primary damage area and an assumed initial compartment temperature around the blast area. Each scenario can begin with simulated prehit information similar to how an actual live fire test would begin. Upon missile impact, the simulator drives environmental variables (thermocouple and smoke density data) in the common database. The SCS reacts to this simulated data in the same manner as it would react to true environmental data. The simulator also recreates damaged and malfunctioning sensors to add an additional degree of realism to the scenario. The SCS will proceed as it would for a real situation controlling simulated water mist and fire main valves. The simulator then responds to the SCS countermeasures by adjusting the environmental sensor data to reflect the performance of the installed systems. (i.e. thermocouple temperatures decrease when the SCS turns on water mist in a compartment, or temperatures increase and fires spread if the user disables water mist in a compartment.) The simulator can be operated by one person, who can also be responsible for simulating the actions of DC personnel on-scene, giving the SCS user a full scenario experience. This simulator was used successfully for familiarizing fleet personnel with the SCS in preparing for the FY01 Demonstration week.

3.12 DC Central Arrangement

The workstations and displays in DC Central are arranged in a human engineered layout to enable effective situation awareness and management of the DC response with three

people in DC Central: a communications/data entry operation, a workstation/ship systems operator, and the DC Officer (see Figure 7).

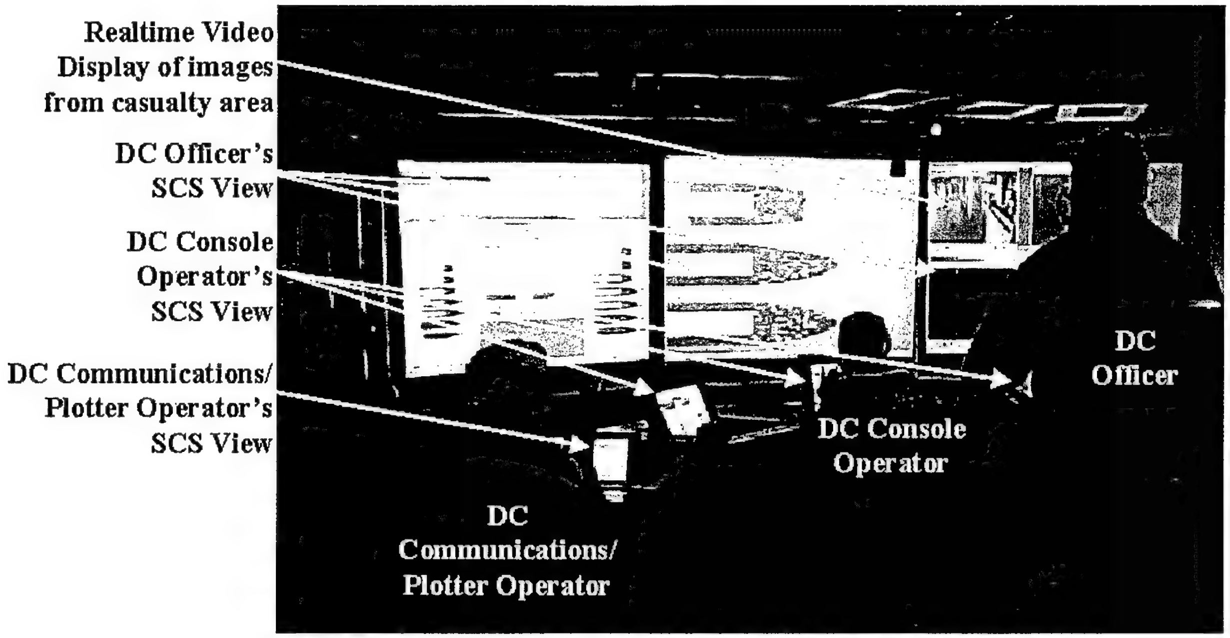

Figure 7. DC Central Photo from FY01 Demonstration

4.0 SCS Architecture

A modular software architecture is used for the SCS so that the extent of redundancy and separation implemented in a particular installation can be adjusted to the degree of survivability required and the resources available (more redundancy and separation would improve survivability, but would cost more to implement). The architecture of the software modules is consistent with the DC functions. There are separate software modules for:

- A generic Compartment Module
- A Zone Module for each watertight subdivision
- A module for each system (i.e. a Fire Main Module and a Water Mist Module)
- A Top Level Module for human-computer interface and personnel management logic and
- A Database Server Module.

Each of the application software modules is designed to operate on a separate computer, or they can operate on one computer or a combination of computers. All of the computers that are running application software modules communicate over a data network. Each SCS applications computer has a complete set of SCS applications software, but loads and runs only its designated application software module (or

modules), thereby keeping the processor burden low and the execution speed high. If the designated primary computer for an application module fails, the application automatically executes on the another SCS computer. For example, the primary fire main control was run on a separate computer for the FY01 Demonstration. If the primary fire main computer was lost, one of the remaining SCS computers would load its copy of the fire main control module from its hard drive and begin monitoring fire main components and making fire main decisions automatically.

In the event a previously lost computer comes back online or a new computer is started, the computer with the most modules running will offload applications to the new computer, thereby distributing the processing load, keeping the response of the system high, and restoring redundancy and separation.

The Database Server Module provides data to and obtains data from all of the applications and provides the interface with other systems, such as the SHADWELL instrumentation system. The Database Server Module could have been made redundant with commercially available database replication software. Due to the expense involved, such database replication software was not utilized for the FY01 Demonstration SCS.

5.0 Engineering the Architecture of Distributed Control Systems

It is not unusual for projects that implement complex control systems to experience cost overruns and schedule delays. Then, even after the added time and expense and substantial changes to the system, the system still does not perform as expected. Such performance problems usually are exacerbated when the system operates in off-design conditions or equipment fails. Such experiences, which are probably representative of the state-of-the-art in industry today, indicate that designing a control system to support DC (when off-design conditions and equipment failures are to be expected) is at the edge of, or exceeding, the state-of-the-art. An objective of the DC-ARM program, therefore, is not only to demonstrate technology to enable reduced DC manning and improved DC performance, but to provide a methodology for implementing the demonstrated technology aboard Navy ships. The key to successful implementation of distributed control systems to function in a DC environment is rigorous engineering of the architecture of the distributed control system.

The basic steps used for the DC-ARM SCS development to engineer the architecture of the distributed control system included:

1. Defining the control decisions that will be executed by the system.
2. Developing the control decision logical architecture.
3. Defining candidate hardware and software architectures.
4. Evaluating the candidate hardware and software architectures and selecting the optimum.

Each of these steps is described briefly below.

5.1 Defining the Control Decisions Executed by the System

The first step in engineering the architecture of the distributed control system is defining and understanding the control decisions that will be executed by the system. In a system such as the DC-ARM SCS where people must interact closely with the systems being controlled, a human-centered approach to the design is vital to the effective operation of the system. A functional analysis methodology was used to define the control decisions that are executed by the SCS and the information that the SCS displays to the DC Officer. The functional analysis also provides an integrated definition of DC functions performed by personnel and by ship systems. The process of developing the functional analysis, and the resulting product, also provide both the user and the developer with a clear, detailed understanding of the performance to be expected from the control system (see Figure 8).

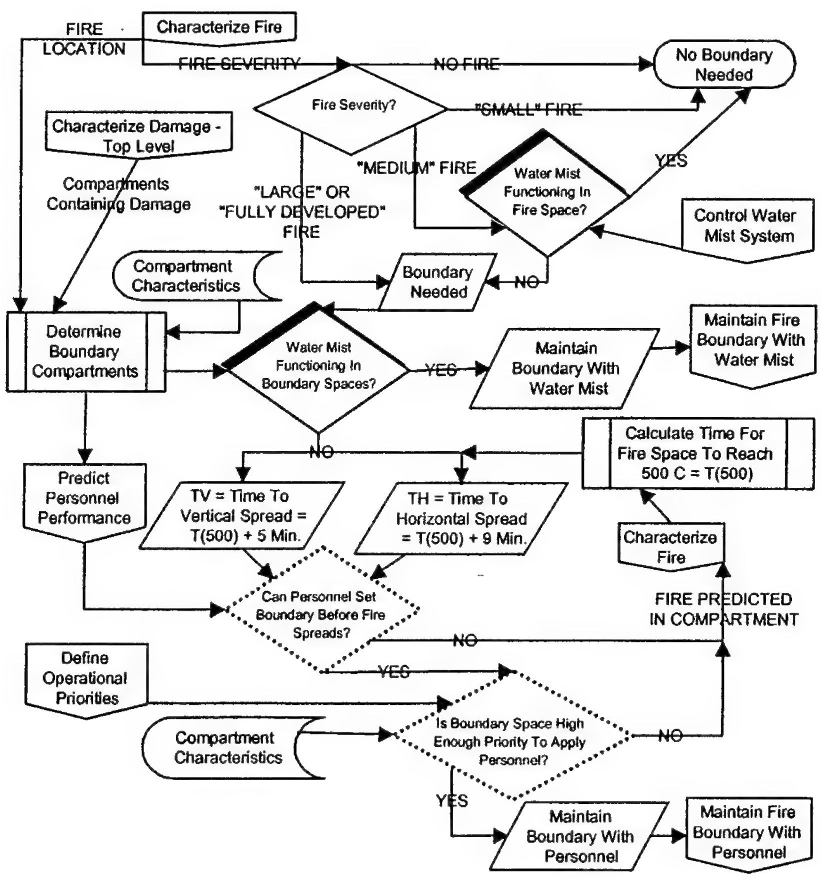

Figure 8. Sample Functional Analysis for Firefighting

5.2 Developing the Control Decision Logical Architecture

The second step in engineering the architecture of a distributed control system is understanding the *logical architecture* of the control decisions. This understanding of the logical architecture is essential to making subsequent decisions about the architecture of the hardware and software that will result in an effective, robust, survivable distributed control system that is practical to develop, install, and maintain.

For the DC-ARM SCS, three levels were defined for the architecture of the control system logic (other control applications could define different levels for the logic architecture):

1. *Device Level Control Logic* is logic that requires inputs only from the device itself to make the control decision. For example, the DC-ARM Smart Valve required only data from pressure sensors installed in the valve itself to make the control decision to close to isolate a rupture. A typical electrical circuit breaker and a conventional pressure-regulating valve are other examples of the application of device level logic. Similarly, from a compartment perspective, *compartment level control logic* would require inputs from only one compartment to make the control decision.

2. *System Level Control Logic* is logic that requires inputs from more than one device in the system to make the control decision. For example, using flow balance among multiple sensing points in a fluid system to identify a rupture is system level logic. Similarly, from a compartment perspective, *zone level control logic* would require inputs from more than one compartment in a zone.

3. *Ship Level Control Logic* requires inputs from more than one system, or more than one zone, or a combination of systems and zones to make the control decision. For the DC-ARM SCS, any control decision involving actions by people is considered ship level control logic.

It is very important to keep in mind that this is a *logical architecture*, it is not a definition for the architecture of the software or hardware that processes the control decisions. Figure 9 is an example of the logical architecture for fire main control.

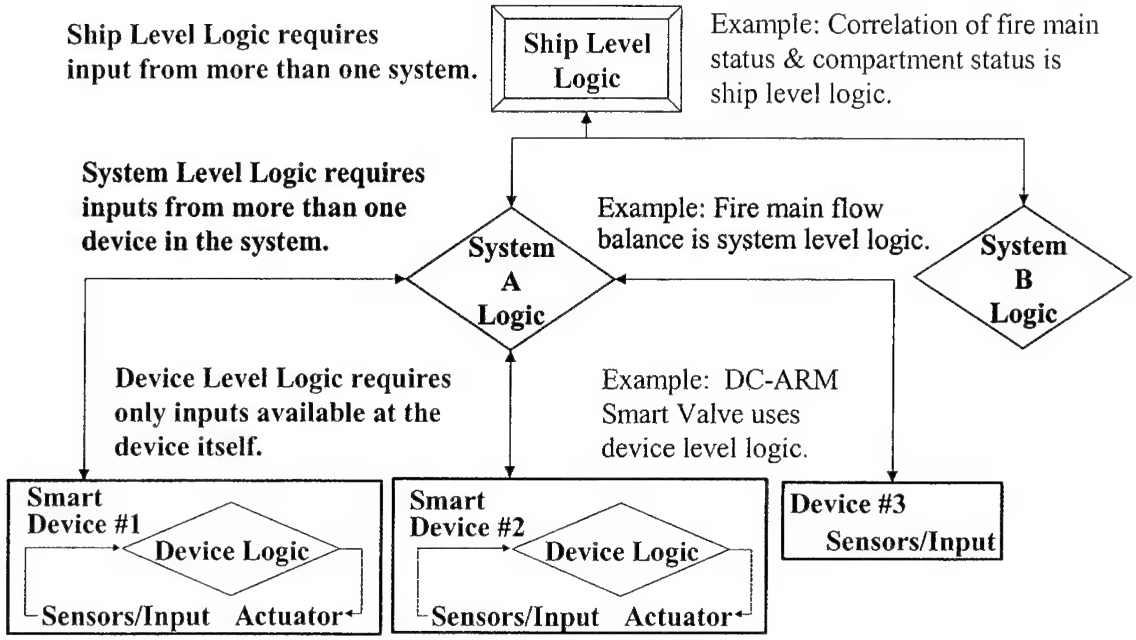

Figure 9. Example Logical Architecture for Fire Main Control

5.3 Defining Candidate Hardware and Software Architectures

The control decision logical architecture provides the basis for the synthesis of candidate hardware and software architectures that meet the same functional requirements. Factors such as processor load, communications load, survivability requirements, and cost constraints should be considered in synthesizing candidate hardware and software architectures. Experience in developing the DC-ARM SCS provided the following lessons:

- Defining boundaries for applications software modules consistent with the levels in the control logical architecture, and consistent with the boundaries in the functional analysis, provide a software architecture that is naturally easy to understand. This simplifies the development of the software and will greatly simplify the maintenance of the software.
- Executing device level logic at the device level (sensors, processor, and actuator all part of the device) provides a very robust (system functions with multiple device failures), highly survivable control capability. True device level control (executing device level logic on device level processors) also inherently supports "plug and play" upgrades to the system. Unfortunately, true device level control could not be achieved for many of the necessary control decisions.

- Executing system level logic or ship level logic on device level processors, on the other hand, would likely result in a control system with a very high communications load (hampering response during a casualty when the data rate is high), and in a control response that would likely be difficult to predict. Such an approach also makes it extremely difficult to achieve a robust capability (i.e. a system that would function in spite of multiple device failures).
- Utilizing a hardware architecture that mirrors the control decision logical architecture would provide a hardware architecture that is naturally easy to understand, thereby simplifying development and maintenance of the system. This also would lead to the maximum level of survivability that could be achieved for the control decisions that need to be executed. Combining levels of control decisions in higher-level processors (i.e. executing system level logic in a ship level computer) is practical and could reduce the cost of the system.

5.4 Evaluating the Candidate Hardware and Software Architectures and Selecting the Optimum

The candidate hardware and software architectures could be evaluated against program selection criteria (relative priorities for survivability, cost, robustness, maintainability, and other program criteria) to select the architecture that is optimum for the program. For the FY01 Demonstration, the SCS was distributed across several PCs. For performance reasons, four PCs were used in Damage Control Central (DCC) to run the SCS graphical displays: One PC for the DC Communications/Plotter Operator, one PC for the DC Console Operator, and two PCs for the DC Officer. One of the DC Officer's PCs ran the standard SCS graphical interface, and the other PC was dedicated to running streaming video from the test area. Remotely there were three PCs responsible for all of the SCS data synthesis. Each PC ran 1/3 of the software modules, thus evenly distributing the workload amongst the three PCs. Three PCs were sufficient to prove the concept of the distributed control system and the dynamic application reallocation discussed in Section 4.0. The SCS display software is separated from the logic software so multiple display stations can be used throughout the ship, and to achieve responsive SCS displays.

There was a common database using Microsoft SQL Server 7.0, which maintained all of the SCS information. No attempt was made to develop a survivable database scheme, because database software manufactures have developed successful methods of database replication. For the purposes of the demonstration, database replication was not demonstrated but it should be noted, that it is available and would be required to make the complete system survivable.

6.0 Conclusions

The DC-ARM demonstration has shown how the SCS, functioning with other DC-ARM technologies such as water mist, can be integrated into a ship's overall DC capability to reduce DC manpower while improving DC performance. Realistic, full scale fire and damage scenarios, conducted with Fleet personnel using the SCS and performing DC actions were utilized to measure and validate the effectiveness of the DC-ARM technology. The DC-ARM technologies met most of, and in many cases exceeded, the quantitative requirements established to significantly reduce DC manning and improve DC performance. Tasks, such as controlling fires, that took on the order of an hour with conventional methods were accomplished in tens of minutes with DC-ARM technology; and tasks, such as identifying the PDA, that took tens of minutes with conventional methods were accomplished in seconds with DC-ARM technology. By identifying the PDA, automatically restoring damaged fire main, and automatically establishing fire boundaries within the first minute after a casualty, the DC-ARM technology dramatically improves the ship's capability to contain and control a casualty. Consequently, fire spread is reduced, injuries are reduced, equipment damage is reduced, and fight-through is improved, all with the utilization of substantially fewer personnel for DC.

The DC-ARM program demonstrated DC manning and performance with the following stages of technology applied:

1. Baseline Demonstration: Improved doctrine and existing technology aboard Navy ships.
2. Remote Manual Control Demonstration: Remote manual control of key systems and improved instrumentation and information systems to enable improved situation awareness.
3. Automated Demonstration: Automated responses to damage, where practical, integrated with complementary manual actions.

These staged demonstrations provide the Navy with benchmarks of technology risk, DC manning, and DC performance that can be used to determine the balance that best suits a particular program for upgrading existing ships or for designing new ships.

In addition to demonstrating the reduced manning and improved performance that can be achieved with DC-ARM technology, the DC-ARM program defined and applied a design methodology for the SCS and integrated systems that will enable the successful application of DC-ARM technology to a specific ship design.

7.0 Recommendations

A triad of testing should be used to fully exercise any new DC system before it is introduced fleet-wide. A recommended test protocol would include:

1. Testing in a realistic DC environment with Fleet personnel, such as the testing typically conducted aboard the SHADWELL. This testing already has been conducted for the DC-ARM SCS.

2. Testing aboard an active ship. Given the rigorous engineering methods used to develop the SCS and the extensive, realistic testing used to demonstrate the effectiveness of the SCS, the SCS is considered ready for pilot testing aboard an active ship. Such a pilot installation could be a fairly straightforward application of the capabilities demonstrated aboard the SHADWELL (compartment information for firefighting and DC and control of the fire main and other installed firefighting systems), or the pilot installation could be extended to include other ship systems.

3. Weapon effects testing of the vulnerability of the systems. The SCS and integrated distributed controls for systems such as the fire main, could be tested at facilities such as the Army proving grounds at Aberdeen, MD, or they could be installed aboard a decommissioned ship used for full-scale live-fire tests. Including the DC-ARM SCS and distributed controls in such testing, which is conducted periodically by the Navy, would provide valuable lessons for the application of this technology to DC functions that must be performed after a ship takes damage.

Although it is unlikely that any system or capability related to DC today has been subjected to such a triad of testing, conducting such tests in a coordinated manner, would provide a high degree of confidence that the expected DC performance would be realized in practice. Of these tests, the SHADWELL testing (item 1.) probably is the most demanding, realistic representation of the DC environment in which people and systems must interact; the DC-ARM SCS is the only Navy information and control system that has gone through such tests. Most of the DC information and control systems being installed aboard ships today have only gone through pilot testing aboard active ships (item 2.). Such pilot Fleet testing is important, but cannot replicate the demands and stresses of a realistic DC environment. Weapon effects testing (item 3.), typically has not been performed for DC systems being installed aboard ships today. Such testing would provide confidence that the systems would perform as expected after the ship is damaged.

Conducting such a triad of tests for the DC-ARM SCS is recommended so that ship designers have the comprehensive lessons learned to effectively apply the technology

and so that the Fleet has confidence that these new capabilities will perform as expected when they are needed the most.

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